



# Seed moisture at physiological maturity in oilseed and confectionary sunflower hybrids in the northern U.S.

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## ABSTRACT

Desiccating sunflower (*Helianthus annuus* L.) to hasten harvest has become common practice in the northern U.S. and can aid in reducing yield loss associated with severe weather, plant degradation, and bird predation. Current recommendations are to apply desiccants to sunflower at 35% or less seed moisture corresponding to physiological maturity (PM). However, evidence suggests PM may occur at higher seed moisture. Therefore, a 2-yr field study was conducted at Prosper, ND, and Morris, MN, with the objective being to model the dynamic relationship of seed dry matter accumulation to moisture content in sunflower seed of two high-oleic oilseed hybrids and one confectionary hybrid to estimate seed moisture content at PM. Between stages R6 and R9 (PM), seed samples were collected from capitulum at 4–7 d intervals. Seeds were separated from the inner, middle, and outer concentric thirds of the capitulum for analysis. Average moisture content across middle and outer seed at PM for both oilseed hybrids was about 40% regardless of environment, but it was 50% for the confectionary hybrid. Inner seed lagged behind middle and outer zones in reaching PM, but only comprises about 11% of total seed on capitulum. Approximately 600–666 °Cd were required for seed to progress from R6 to PM for the oil hybrids and 486–612 °Cd for the confectionary hybrid. For both types of hybrids, PM occurred about 3 d later in middle seed as compared to outer seed. Indeed, our results indicate modern sunflower hybrids can be desiccated at higher seed moisture than currently recommended without sacrificing yield loss due to not reaching PM.

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## 1. Introduction

Desiccants are becoming more commonly used as a harvest aid to hasten sunflower harvest. Desiccating sunflower as early as possible without sacrificing yield can be a desirable management practice to hasten harvest thus avoiding yield-losses due to bird predation, diseases, lodging, and seed shattering (Gubbels and Dedio, 1994). Desiccation can be especially useful for hastening the harvest of genotypes that retain leaves even after the capitulum (i.e., head) has begun to senesce (Robinson, 1983), and especially for ‘stay-green’ sunflower hybrids that senesce slower than conventional hybrids (Larson et al., 2008). In the northern U.S., during autumn when sunflower is typically harvested, the frequency of cool, wet weather increases, which can delay harvest. Timely application of desiccant to sunflower in such a climate can result in harvesting up to 26 d earlier than for an un-desiccated crop (Gubbels and Dedio, 1985).

Termination of seed filling occurs at physiological maturity (PM), the point of maximum seed dry matter accumulation, and hence, when maximum grain yield is achieved (Egli, 1998). Thus, desiccant application to a grain crop such as sunflower should be applied at or just after PM to maximize yield. The most accurate method to assess PM is to measure seed dry matter accumulation to determine when it ceases (Egli, 1998). However, this is not practical for most farmers. Producers can greatly benefit from a practical, yet reliable method for identifying or predicting PM. Attempts have been made to use simple visual cues such as the coloration of the capitulum (Robinson, 1983; Schneiter and Miller, 1981; Connor and Sadras, 1992) to estimate PM, but this can be subjective. A more objective and practical approach that has worked well in other grain crops (Egli, 1998; Calderini et al., 2000) is to model the relationship between seed dry matter accumulation and moisture to determine the percent moisture content that corresponds to maximum seed dry weight. However, using this relationship, the seed moisture content at PM can vary among different species. For instance, Egli and TeKrony (1997) reported that seed moisture at PM was 55–59% for soybean [*Glycine max* (L.) Merr.], 44% for wheat (*Triticum aestivum* L.), and 33–38% for corn (*Zea mays* L.).

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Recommendations of when to apply desiccants to sunflower prior to harvest are typically based on the seed moisture content at PM, and currently, it is recommended that preharvest aids such as glyphosate and desiccants paraquat and saflufenacil be applied at 35% or less seed moisture (Zollinger, 2011). However, there is uncertainty about what the seed moisture content of sunflower seeds is at PM. Evidence in the literature indicates that it may range anywhere from 15% (Kole and Gupta, 1982) to 40% (Anderson, 1975), and may even be as high as 50% (Gubbels and Dedio, 1985). Because of the economic importance of sunflower oil, most work to date on characterizing dry matter accumulation as a function of seed moisture content has focused on oilseed cultivars. However, confectionary (i.e., non-oilseed) cultivars of sunflower are an important commodity in the U.S. Non-oilseed cultivars made up 25% of planted sunflower hectares in the U.S. in 2010 (USDA-NASS, 2011). Yet, much less is known about the relationship of seed moisture and dry matter accumulation in these genotypes.

The disparity in the literature with regard to seed moisture content at PM may be related to the nature of the seed samples used for analysis across studies. Differences in growth environment, especially due to temperature (Ploschuk and Hall, 1995) and genotype (Rondanini et al., 2007) can influence this relationship. Other factors such as differences in the timing of flowering and seed filling among plants and/or within individual capitulum might have an influence as well. The initiation of flowering among sunflower within a population of plants in a field can occur over several days (Robinson, 1983; Connor and Sadras, 1992). Likewise, flowering in an individual capitulum progresses from the outer periphery towards the center, and depending on the number of floral circles present, this can take up to 5–7 d (Seiler, 1997). Moreover, as breeders have selected for oil content in sunflower, the proportion of embryo or kernel to total grain has increased (López et al., 2000). Therefore, the proportion of pericarp to total seed mass can vary considerably among cultivars (Rondanini et al., 2007) and this too might affect the dynamics of dry matter accumulation and seed moisture.

Therefore, depending on the cultivar, where the seed is sampled on the capitulum, and whether there is a discrepancy in flower timing among plants sampled, all could conceivably effect the determination of seed moisture content at PM. Rondanini et al. (2007) considered some of these factors in estimating seed moisture at PM in eight different sunflower genotypes differing in maximum seed weight and proportion of pericarp to total grain across several different experiments and seeds sampled from different zones on the capitulum. Using a conditional bi-linear routine to model the relationship of seed dry matter accumulation to moisture content, Rondanini et al. (2007) found the PM generally corresponded to a moisture content of 38%, although one of the genotypes was significantly lower than the others. They concluded that using moisture content to predict PM was a relatively reliable method.

Desiccating sunflower at seed moisture 5–10% higher than what is currently recommended (i.e., 35%) without a significant yield loss due to termination of seed filling prior to PM, could translate into harvesting several days to even a week or more earlier. In autumn, when sunflower is harvested in the northern U.S., earlier harvest could significantly reduce yield losses due to seed shattering and lodging of plants caused by extreme weather, and predation from migrating birds. The primary objective of the present study was to model the relationship of seed dry matter accumulation to moisture content in seed from the periphery to the center of the capitulum to estimate the percent seed moisture at PM in two commercial high oleic acid oil hybrids and one confectionary hybrid of sunflower grown in the field.

## 2. Materials and methods

### 2.1. Cultural practices

This study was conducted in 2008 and 2009 on a Barnes loam soil (fine-loamy, mixed, superactive, frigid Calcic Hapludoll) at a field site located 24 km northeast of Morris, Minnesota (45°35'N, 95°54'W) and on a Perella silty clay loam (fine-silty, mixed, superactive, Typic Endoaquolls) at the North Dakota State University research farm at Prosper, ND (46°5'N, 97°1'W). The previous crop for both years of the study in MN and ND was spring wheat.

The experimental design was a randomized complete block replicated four times. Two high oleic acid oilseed sunflower (*Helianthus annuus* L.) hybrids, Croplan Genetics 378 and Mycogen 8N-272, and one confectionary hybrid, Red River Commodities 2215, were used in the study. Prior to sowing seed, 112, 34, and 34 kg ha<sup>-1</sup> of N-P-K was incorporated into the soil for fertility at the Morris site. Phosphorus was added as diammonium phosphate and N was added as urea (93 kg ha<sup>-1</sup>) and diammonium phosphate (19 kg ha<sup>-1</sup>). At the Prosper site, N was the only nutrient limiting the potential for 2800 kg ha<sup>-1</sup> seed yields and therefore, was amended with urea such that the total soil N (that present, plus amended) was 140 kg ha<sup>-1</sup> both years prior to planting in the spring (Franzen, 2010). At Morris, trifluralin (1.1 kg ai ha<sup>-1</sup>) was pre-plant incorporated with the fertilizer for weed control in 2008. In 2009, pendimethalin was used for weed control at a rate of 1.6 kg ai ha<sup>-1</sup>. At Prosper, trifluralin (1.1 kg ai ha<sup>-1</sup>) was pre-plant incorporated both years. Hand weeding supplemented further control as needed at both sites.

All three hybrids were sown June 1 of both years in rows spaced 76 cm apart. The two oil hybrids (i.e., 378 and 8N-272) were sown at a rate of 61,750 seed ha<sup>-1</sup> and thinned to a plant population density of 54,340 plants ha<sup>-1</sup> following emergence (Berglund, 2007). The confectionary hybrid was sown at 49,400 seed ha<sup>-1</sup> and thinned to a plant population density of 41,990 plants ha<sup>-1</sup> following emergence (Berglund, 2007). The individual plot sizes were 12 rows wide (9.1 m) by 7.6 m long. Two unsampled rows on each side of each plot were used as border. At the MN site in 2009, the sunflower hybrids were treated August 2 with lambda-cyhalothrin at a rate of 0.02 kg ai ha<sup>-1</sup> primarily to control sunflower midge (*Contarinia schulzi* Gagné). At Prosper in 2009, red sunflower seed weevil (*Smicronyx fulvus* LeConte) and the banded sunflower moth (*Cochylis hospes* Walsingham) were controlled with weekly applications of exfenvalerate (0.05 kg ai ha<sup>-1</sup>) beginning at growth stage R5.1 (Kondel, 2011). Larval damage to developing seed from these pests did not pose a problem at Prosper in 2008.

### 2.2. Seed sampling and moisture measurement

The system of Schneiter and Miller (1981) was used to growth stage plants. At the R5.1 stage, approximately 30 ± 5 sunflower capitula were tagged per plot for future sampling and seed analysis. This was done during the first two weeks of August in both years. The oil hybrid 8N-272 reached R5.1 consistently 4–5 d earlier than the other two hybrids, which were similar in their timing from sowing to R5.1. Starting at R6 stage, one or two capitula per plot were sampled at 4–7 d intervals until seed moisture was 20% or less, which usually resulted in 8–10 sampling dates per hybrid per year and site. Sampled capitulum were put into tightly sealed plastic bags and immediately transported to the lab where they were processed. These steps were taken to prevent moisture loss from the seeds.

The capitulum were split in half and divided concentrically into thirds with the inner-most 1/3rd of seed referred to as “inner seed,” the next concentric 1/3rd of seed referred to as “middle seed,” and the outer concentric 1/3rd referred to as “outer seed.” From

each concentric zone, 125 seeds were sampled to obtain their fresh and dry weight. Dry weight was measured after being placed in a forced-air oven at 80 °C for 72 h (Morris location) or 105 °C for 24 h (Prosper location). Seed were cooled in a desiccator before weighing. In both instances, seeds were dried to constant weight. Growing degree days were calculated as:  $GDD = \sum (T_{max} + T_{min}/2) - T_{base}$ , where  $T_{max}$  and  $T_{min}$  are daily maximum and minimum air temperature, respectively, and  $T_{base}$  is the base temperature, which was taken as 4 °C for sunflower (Villalobos and Ritchie, 1992). Air temperature and precipitation data were collected at weather stations that were located at the study sites.

### 2.3. Statistical analysis and seed moisture at physiological maturity

Data for mean seed weight were plotted with respect to moisture content and fit, using weighted regression with standard weights of 1/variance, to a logistic function of the form  $Y = A/[1 + (x/b)^c]$  where  $Y$  is the mean seed weight,  $x$  is the percent moisture and  $A$  is the maximum seed dry weight. Equations were developed with TableCurve 2D (version 5.0, Systat Software, San Jose, CA) and used for nonlinear statistical comparison. Full and reduced model comparisons were made using the methods of Neter et al. (1990) to determine whether there were significant differences between equations at the  $P \leq 0.05$  level for year, field site, cultivar, and seed position on the capitulum for the relationship of seed weight as a function of moisture content. Initial analysis showed no significant differences between years but there were between field sites, and there was not a significant year  $\times$  site interaction. Therefore, data were combined for years but not for field sites for further analysis.

The percent seed moisture at physiological maturity was obtained by calculating the moisture content at the seed dry weight whose 95% confidence interval overlapped that of the maximum seed dry weight (parameter  $A$  of the logistic function described above).

## 3. Results and discussion

### 3.1. Climate conditions

During the study, climate conditions at the Prosper, ND, site generally tended to be cooler and wetter than the Morris, MN, field site (Table 1). In 2008, the North Dakota site received considerably more precipitation, especially during August and September, which were critical months for seed filling. During this period, the Minnesota site received only 119 mm of precipitation while the North

**Table 1**  
Monthly average air temperature and precipitation for the sunflower growing seasons in Morris, MN, and Prosper, ND.

Year	Month	Avg. air temperature (°C)		Precipitation (mm)	
		MN	ND	MN	ND
2008	June	18.2	17.2	97	164
	July	21.8	20.5	31	75
	August	20.5	20.3	58	77
	September	15.6	14.7	61	180
	October	8.1	7.8	104	99
	Mean	16.8	16.1	Total	351
2009	June	18.2	17.5	41	67
	July	19.2	18.4	20	25
	August	18.8	17.7	70	57
	September	17.4	17.3	31	53
	October	4.5	4.0	128	128
	Mean	15.6	15.0	Total	290

**Table 2**

Comparison of the nonlinear relationship between seed dry matter and moisture content for three sunflower hybrids by seed position on the capitulum. For comparisons of hybrids by seed position at a given field site, different letters denote significant difference at the  $P \leq 0.05$  level.

Field site <sup>a</sup>	Seed position	Sunflower hybrid		
		378	8N-272	2215
MN	Inner	B	B	A
	Middle	B	B	A
	Outer	B	C	A
ND	Inner	B	B	A
	Middle	B	B	A
	Outer	B	B	A

<sup>a</sup> The interaction of field site with the relationship between dry matter and moisture content was significant, but the year effect was not. Therefore, data for both years were combined by field site.

Dakota site received over twice that amount (257 mm). The rainfall pattern, amount per month and total for the growing season, was more similar between sites in 2009. However, both sites received less precipitation in 2009 than 2008.

### 3.2. Comparison of seed dry matter accumulation and moisture content dynamics among hybrids and seed position

At each field site and seed position on the capitulum, the response of seed dry weight as a function of moisture content was similar between the two oilseed hybrids, but not the confectionary hybrid (Table 2). For all three hybrids, characteristics of the inner seed tended to be much different than seeds from the outer and middle concentric thirds of the capitulum (Table 3). Inner seeds always had less mass than outer and middle seed, and except in one instance (i.e., 8N-272 in Minnesota; Fig. 2), they had greater moisture content at PM than the other seeds (Figs. 1–3). Lack of filling is characteristic of seed near the center of the capitulum and this can vary with cultivar (Seiler, 1997). This was likely the primary reason for the consistent difference in response of inner seed compared to seed from the middle and outer zones of the capitulum. Moreover, the inner concentric third of the capitulum comprises only a small portion of total seed (i.e., 11%) for the capitulum. Therefore, the remainder of the discussion will primarily emphasize the characteristics of the outer and middle seed with respect to predicting PM based on moisture content as these zones comprised the majority of total seed.

### 3.3. Dynamics of seed dry matter accumulation as a function of seed moisture

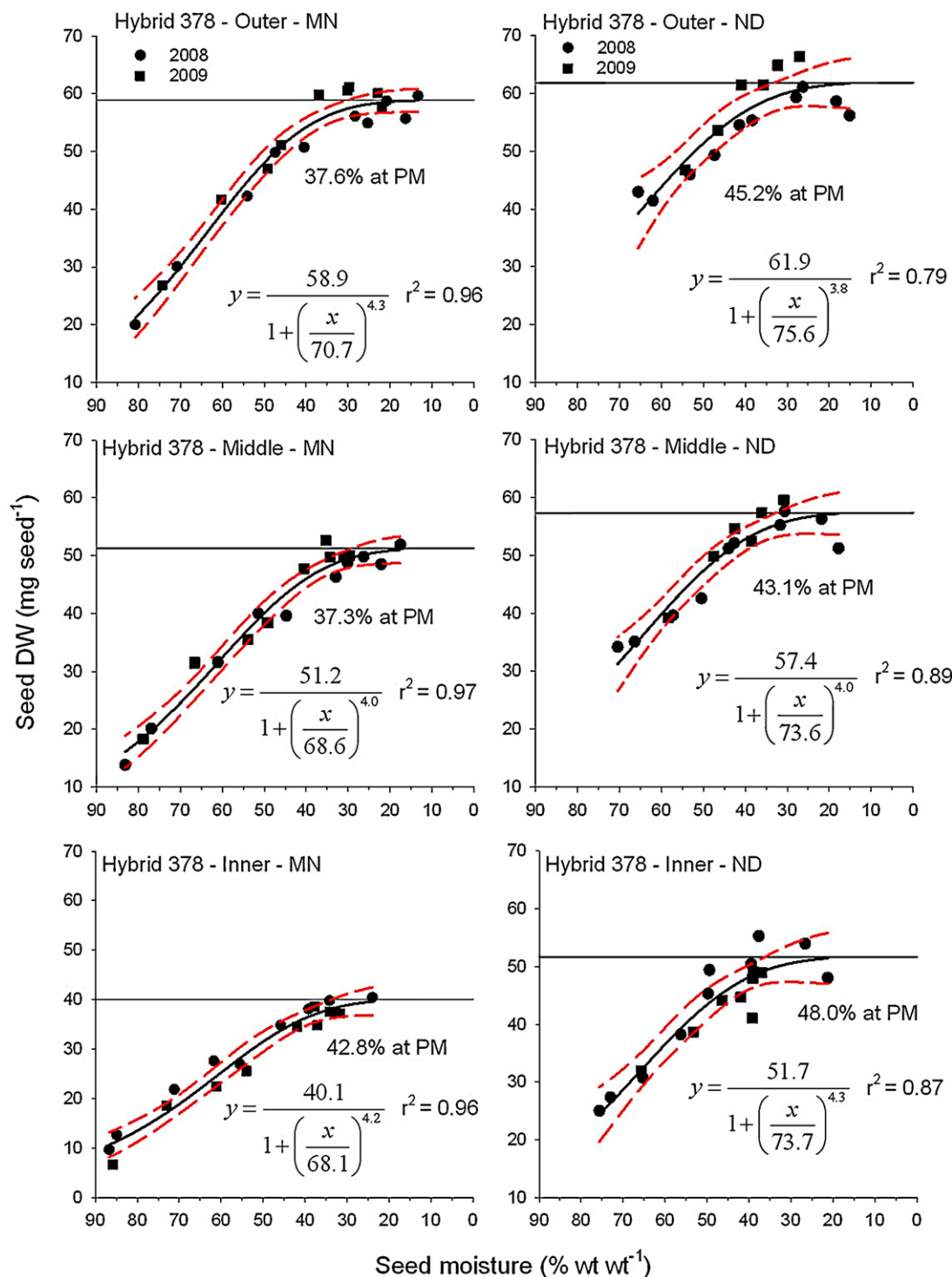
The relationship of dry matter accumulation to seed moisture as seeds developed was modeled well with the logistic function used.

**Table 3**

Comparison of the relationship between seed dry matter and moisture content for seed position on the capitulum by sunflower hybrid at each field site. For comparisons of seed position by hybrid at a given field site, different letters denote significant difference at the  $P \leq 0.05$  level.

Field site	Hybrid <sup>a</sup>	Seed position		
		Inner	Middle	Outer
MN	378 + 8N-272	A	A	B
	2215	C	B	A
ND	378 + 8N-272	B	A	A
	2215	B	A	A

<sup>a</sup> Data for the two oilseed hybrids were combined for both years based on the similarity of their response (Table 2).

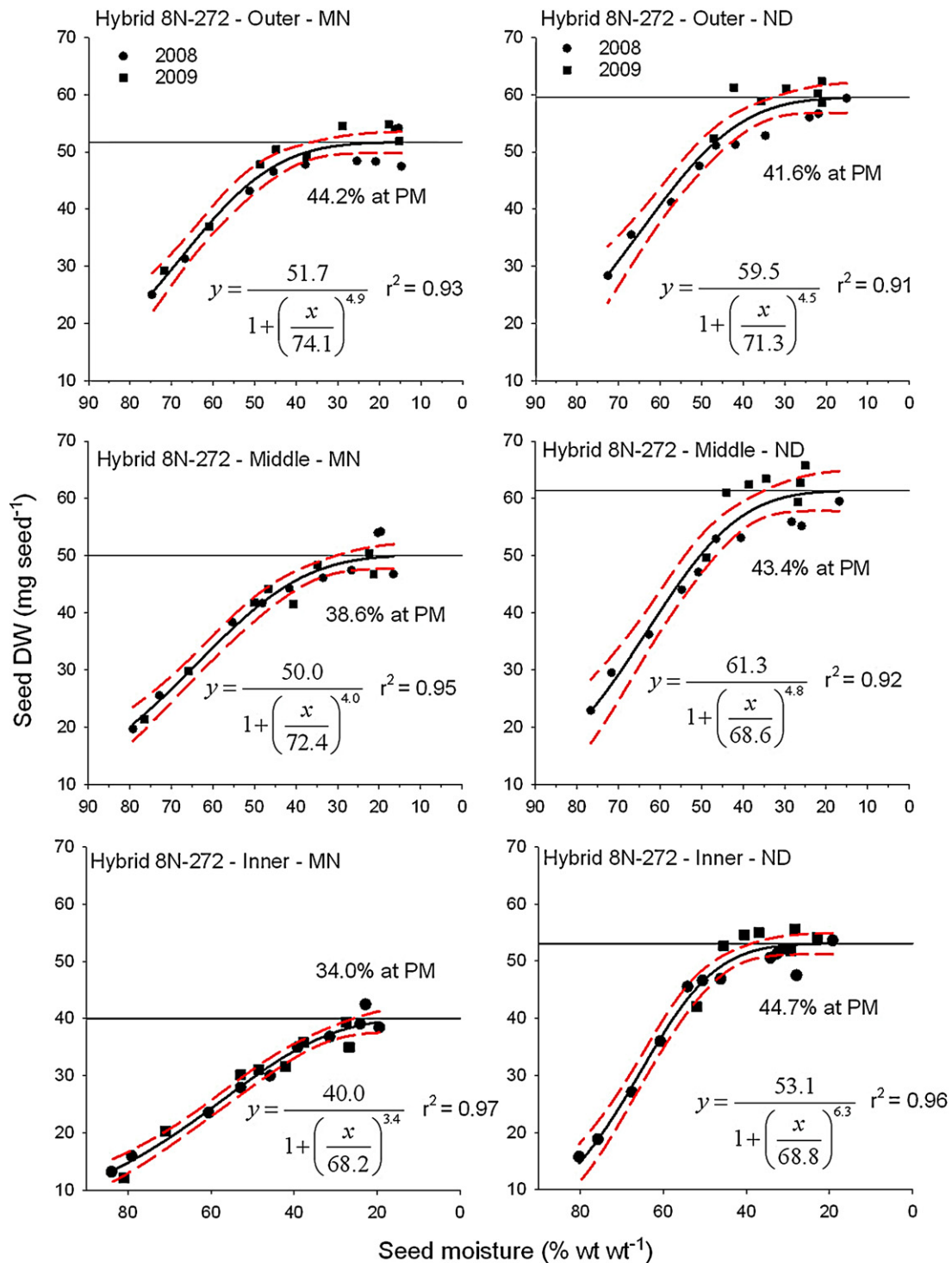


**Fig. 1.** Modeled relationship between seed dry weight as a function of moisture content from different capitulum positions for oilseed hybrid 378 grown in Minnesota and North Dakota. Individual values are means,  $n=4$  (each replication is based on 125 seeds). The horizontal reference lines denote maximum individual seed weight, dashed lines mark the 95% confidence interval, and the estimated moisture content at PM is given for each seed position.

In most cases  $r^2$  values were  $\geq 0.88$  (Figs. 1–4). For oil hybrid 378, as with the other hybrids, individual seed mass was greatest for outer seed followed by middle and then inner seed (Fig. 1). When compared between field sites, both outer and middle seed mass and moisture content were greater at PM for hybrid 378 in North Dakota than for Minnesota. Averaged across outer and middle seed, moisture content at PM was 44.2% for 378 at North Dakota compared to 37.5% at Minnesota (Fig. 1).

Averaged across outer and middle seed of hybrid 8N-272, the moisture content at PM was similar between field sites (41.4% at MN and 42.5% at North Dakota), but clearly, seed mass was again greater at ND, averaging  $60.4 \text{ mg seed}^{-1}$ , compared to  $50.9 \text{ mg seed}^{-1}$  for Minnesota (Fig. 2). With respect to just outer and middle seed for both oilseed hybrids across both field sites, seed moisture at PM ranged from 37.3 to 45.2% (Figs. 1 and 2). This is 2.3–10.2% higher than the 35% moisture level that is generally recommended for



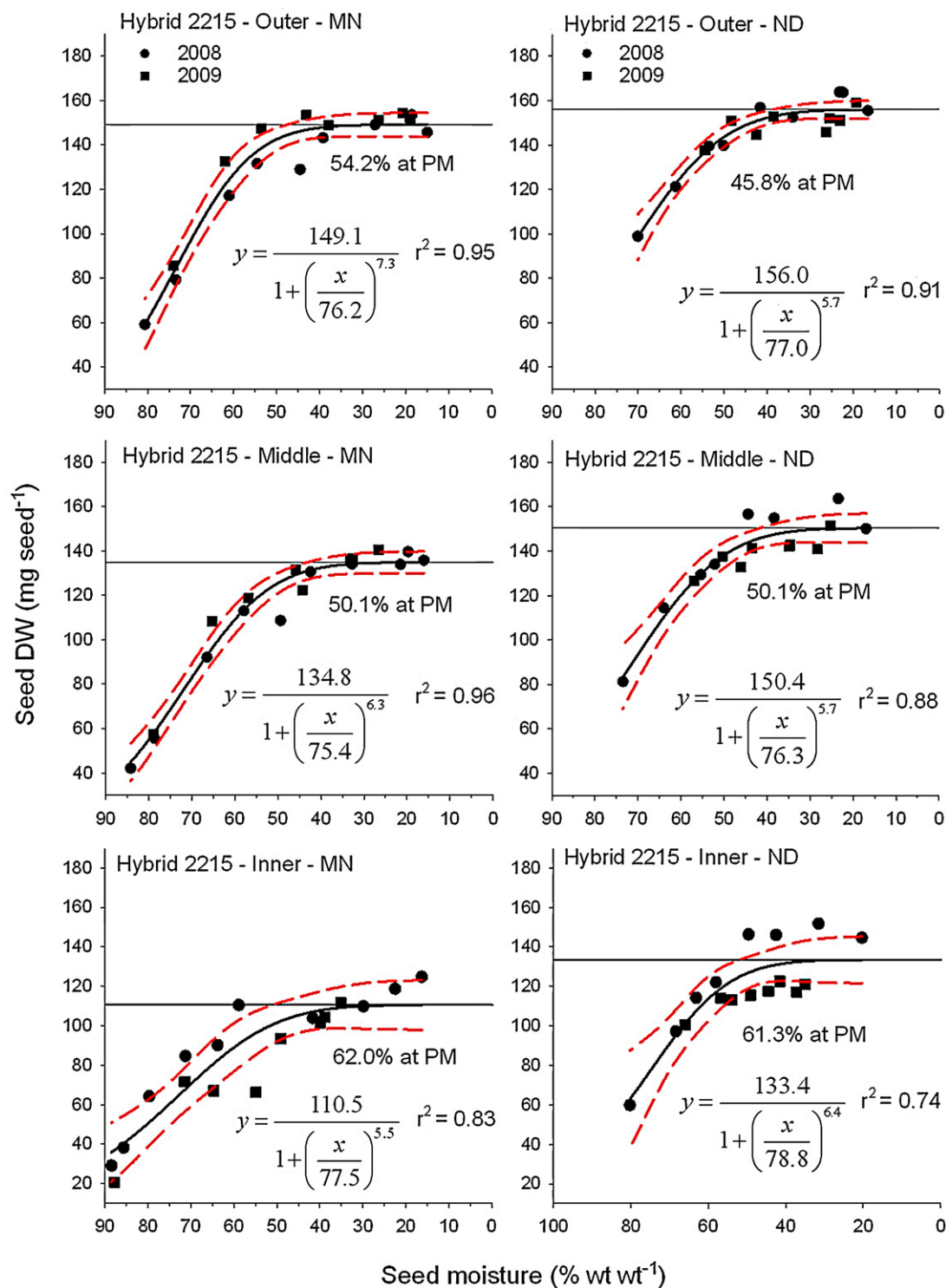


**Fig. 2.** Modeled relationship between seed dry weight as a function of moisture content from different capitulum positions for oil hybrid 8N-272 grown in Minnesota and North Dakota. Individual values are means,  $n=4$  (each replication is based on 125 seeds). The horizontal reference lines denote maximum individual seed weight, dashed lines mark the 95% confidence interval, and the estimated moisture content at PM is given for each seed position.

desiccant application (Zollinger, 2011). In a 3-yr field study conducted in Morden, Manitoba, Gubbels and Dedio (1985) found that for two sunflower cultivars studied, desiccating at 45% seed moisture resulted in no significant loss of seed yield or quality, and in one of the three seasons they reported no yield loss when plants were desiccated at 50% moisture. Although results from our study suggest that PM of sunflower seed occurs at higher moisture content than currently recommended for desiccation, the variation we

observed between locations also suggests that it is difficult to propose a specific recommendation that suits all environments.

The confectionary hybrid, 2215, responded differently than the two oilseed hybrids with respect to the relationship of seed weight versus moisture content (Table 2). Seeds of 2215 were considerably heavier than those of the oilseed hybrids, and again, seeds from the North Dakota site were heavier than those from Minnesota (Fig. 3). Interestingly, across field sites and seed position,

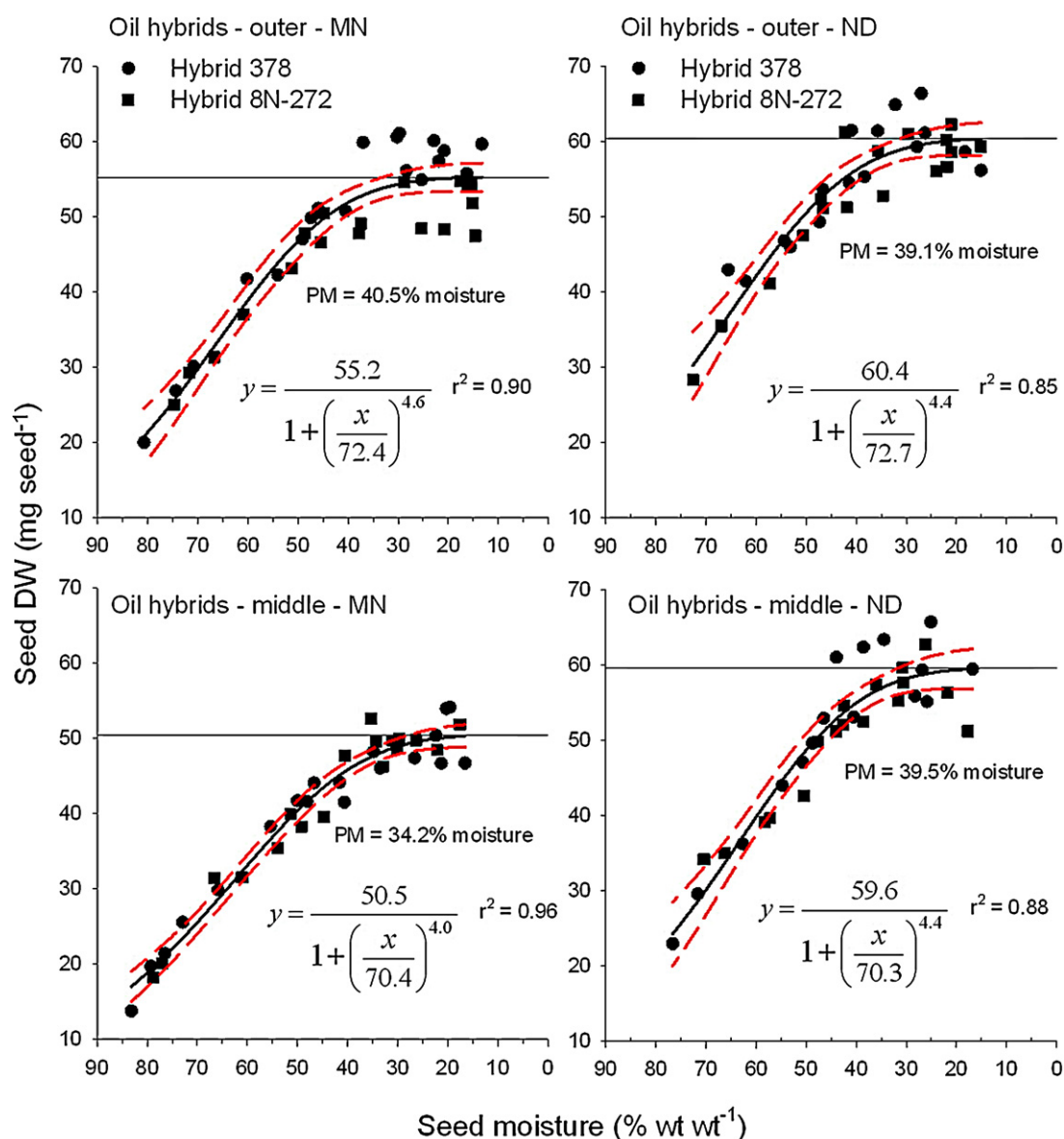


**Fig. 3.** Modeled relationship between seed dry weight as a function of moisture content from different capitulum positions for the confectionary hybrid 2215 grown in Minnesota and North Dakota. Individual values are means,  $n=4$  (each replication is based on 125 seeds). The horizontal reference lines denote maximum individual seed weight, dashed lines mark the 95% confidence interval, and the estimated moisture content at PM is given for each seed position.

moisture content at PM was considerably higher for hybrid 2215 than the oilseed hybrids. Averaged across outer and middle seed, moisture content at PM was 52.2% at Minnesota and 48.0% at North Dakota for hybrid 2215 (Fig. 3), which was as much as 14.8% higher than the oilseed hybrids. Our results for hybrid 2215 appear to corroborate the findings of Gubbels and Dedio (1994) who reported that when a non-oilseed sunflower cultivar ('Sundak') was desiccated at seed moisture content as high as 53%

there was no loss in seed yield compared to a non-desiccated control.

The greater moisture content at PM for the confectionary hybrid might be related to the greater proportion of its pericarp (i.e., hull) to whole seed as compared to that for the oilseed hybrids (López et al., 2000). Rondanini et al. (2007) found little difference in the seed water content estimated at PM in eight different sunflower genotypes whose proportion of seed hull to total seed weight



**Fig. 4.** Modeled relationship of seed dry weight as a function of moisture content of outer and middle seed for both oil hybrids combined. Individual values are means,  $n=4$  (each replication is based on 125 seeds). The horizontal reference lines denote maximum individual seed weight, dashed lines mark the 95% confidence interval, and the estimated moisture content at PM is given for each seed position.

ranged from 17 to 35% (for peripheral or outer seed). However, in our study, the proportion of seed hull to total seed for the confectionary sunflower hybrid (2215) was 47% (Table 4). This was more than twice as high as that for the oilseed hybrid 8N-272 (Table 4) and considerably greater than any of the genotypes in Rondanini et al.'s (2007) study. The percent pericarp of seed for hybrids 378 (27%) and 8N-272 (21%) in our study (Table 4) is more similar to the genotypes used by Rondanini et al. (2007).

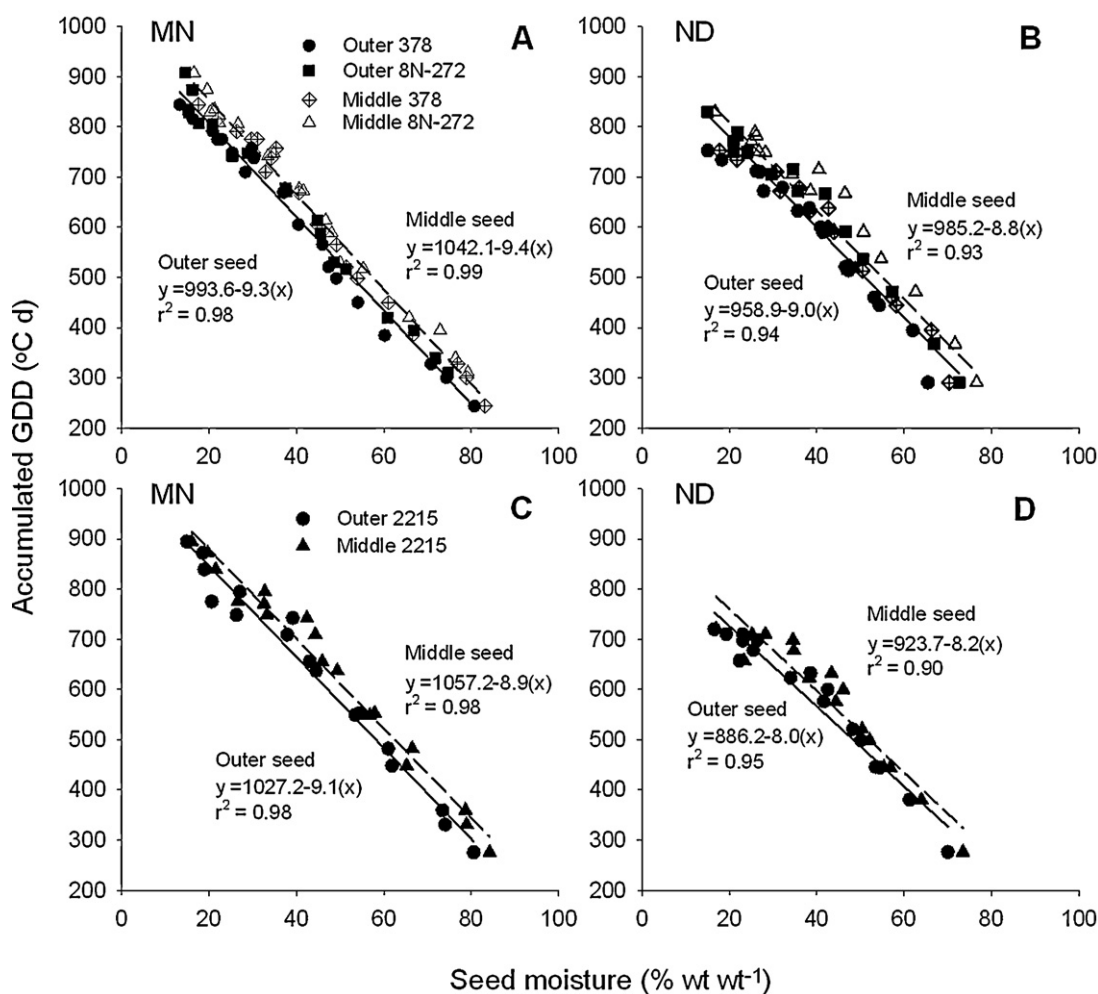
**Table 4**

Partitioning of seed mass between pericarp and embryo for mature outer seed of the three hybrids studied. Values are means  $\pm$  SE,  $n=4$ . Each replication consisted of 10 seeds. The seeds used were collected in the final harvest during 2008.

Hybrid	Pericarp dry wt. (g per 10 seed)	Embryo dry wt. (g per 10 seed)	Pericarp % of total seed
2215	0.74 $\pm$ 0.03	0.85 $\pm$ 0.02	47 $\pm$ 1
378	0.19 $\pm$ 0.02	0.52 $\pm$ 0.04	27 $\pm$ 1
8N-272	0.11 $\pm$ 0.003	0.41 $\pm$ 0.01	21 $\pm$ 0.3

Across sunflower hybrids and seed position on the capitulum, seed mass was always greater at the North Dakota field site than the Minnesota site (Figs. 1–3). This was likely due to environmental differences. Although soil type at both locations were relatively similar, and the previous crop the same (i.e., spring wheat), climate conditions at the North Dakota site tended to be cooler and wetter than the Minnesota site (Table 1). Exposure of grain crops to periods of water deficit and high temperatures can greatly influence seed filling (Ploschuk and Hall, 1995; Saini and Westgate, 2000). Alternatively, potential differences in plant available soil N during plant development might have affected seed size. Increased soil N availability, particularly during floret initiation through anthesis of sunflower, can result in increased seed size (Steer et al., 1984).

Although both oilseed hybrids were similar in their response of seed dry matter accumulation to moisture content (Table 2), there was variability of the response across seed position on the capitulum between field locations. When both oil hybrids were combined for analysis, the response for outer and middle seed was similar in North Dakota, but not in Minnesota (Table 3). When the response



**Fig. 5.** The relationship of accumulated growing degree days (GDD) as a function of seed moisture between R6 and seed maturity for the two oil hybrids combined from Minnesota (A) and North Dakota (B) and for the confectionary hybrid from Minnesota (C) and North Dakota (D). Individual values are means,  $n = 4$  (each replication is based on 125 seeds). GDD were calculated using a base temperature of 4 °C.

of seed weight to moisture was combined for the oilseed hybrids separately for outer and middle seed, the seed moisture at PM was found to be 39–41%, except for the instance of the middle seed in Minnesota (Fig. 4). Our findings for the two oilseed hybrids are similar to that reported by Anderson (1975) and Rondanini et al. (2007) of 40 and 38%, respectively, but greater than that reported by others such as Kole and Gupta (1982), Browne (1978), and Robertson et al. (1978) who reported 15, 29, and 36% seed moisture at PM, respectively.

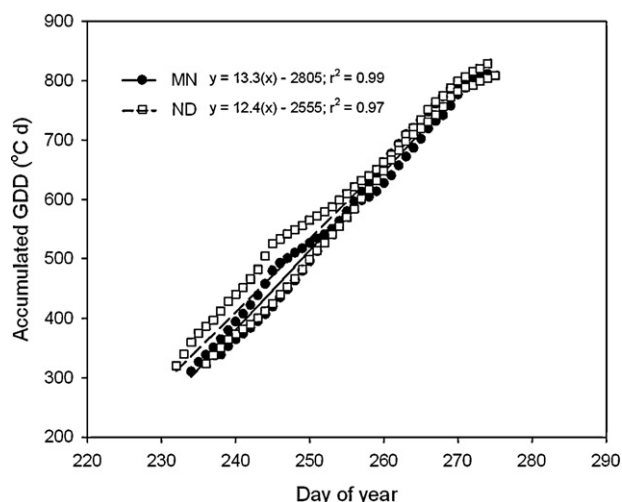
#### 3.4. Relationship of accumulated growing degree days to seed development

Seed drydown during seed development, from R6 to full maturity, followed a linear relationship with respect to growing degree days (GDD) as shown in Fig. 5. This relationship is convenient for further helping producers to predict when to desiccate sunflower, as most growers have access to daily temperature data either through the Internet or by access to a near-by weather station. In the present study there was no difference in the relationship of seed moisture to GDD for the oilseed hybrids, so they were combined for linear regression (Fig. 5). However, with respect to position on the capitulum, middle seed required more GDD to reach the same moisture content as outer seed, regardless of hybrid. For example, in Minnesota for the oil hybrids, outer seed required

622 °Cd to reach a moisture content of 40%, while middle seed required 666 °Cd to reach 40% moisture (Fig. 5A). The difference in accumulated GDD between these two (44 °Cd) translated into about a 3 d lag, when using the slope of the linear relationship of GDD to day of year (DOY) in Minnesota during seed development (Fig. 6). In North Dakota, outer seed reached 40% moisture at about 600 °Cd and middle seed at 633 °Cd (Fig. 5B), and again the difference translated into about a 3 d lag (Fig. 6). This lag in seed drying is expected since not only flowering, but also seed development, progresses in sunflower from the periphery of the capitulum towards the center (Schneider and Miller, 1981; Connor and Sadras, 1992; Seiler, 1997).

The amount of accumulated GDD for developing seeds of the oilseed hybrids to reach 40% moisture, regardless of seed position, was 44–47 °Cd less than that required to reach 35% (Fig. 5A and B; based on linear equations). Based on the equations derived from the relationship of accumulated GDD to DOY at the Minnesota and North Dakota sites (Fig. 6), 40% seed moisture occurred at least 3–4 d earlier than 35% moisture. Although this is not a large amount of time, it does allow a larger window of opportunity to apply desiccant under ideal weather conditions, which can translate into earlier harvest, making a significant difference in some years for avoiding crop-loss resulting from severe weather and/or bird predation.





**Fig. 6.** Accumulated growing degree days (GDD) as a function of day of year between R6 stage and full seed maturity of sunflower at Minnesota and North Dakota. For each site, data for 2008 and 2009 are combined for regression. Equations for the linear regression of the response for each field site are given in the graph.

Even more striking were differences in accumulated GDD between 35% moisture and that of 50%, which we found to coincide with PM for the confectionary hybrid (i.e., 2215). Across field sites and seed position, the number of GDD to reach 50% seed moisture ranged from 120 to 137 °C d less than that required to reach 35% moisture (Fig. 6C and D). This translated into a 9–12 d difference (Fig. 6), indicating that the confectionary hybrid could be desiccated nearly 2 weeks earlier than presently recommended (i.e., 35% seed moisture), without sacrificing yield because of not reaching PM. In addition to the importance of early desiccation and harvest for reducing yield loss, the earlier a desiccant is applied in sunflower growing areas of Minnesota and North Dakota, the greater the chance of taking advantage of warmer, drier weather that can further aid in hastening drydown of the treated crop.

#### 4. Summary and conclusions

Using a non-linear regression technique for modeling the relationship of sunflower seed dry matter accumulation and seed moisture to estimate PM, we have shown that PM for two modern oilseed hybrids occurred at approximately 40% moisture, while that for a confectionary hybrid was 50%. We have also shown that this relationship was relatively constant across environments and across the capitulum for seeds in the outer and middle concentric zones. However, the inner seed (i.e., at the center) of the capitulum, which only makes up about 11% of the total seed, responded differently than the outer and middle seed. The number of accumulated GDD from R6 to PM for the oil hybrids ranged from 599 to 622 °C d for outer and 633 to 666 °C d for middle seed. The period from R6 to PM was even shorter for the confectionary hybrid, which ranged from 486 to 572 °C d for outer and 515 to 612 °C d for middle seed. Overall, the data indicate that modern sunflower hybrids could be desiccated earlier at seed moisture content greater than that currently recommended (i.e., 35%) without yield loss, especially confectionary (i.e., non-oil cultivars) sunflower, whose seed have a large proportion of pericarp. However, because PM in middle seed lagged about 3 d behind outer seed, desiccant application should be based on when the middle concentric third of seed around the capitulum reach PM. Our results further suggest that if moisture content is used as criterion for when to apply desiccant to sunflower that a wider range of confectionary sunflower genotypes be tested.

Our study clearly showed substantial differences in seed moisture content at PM can exist between confectionary and oilseed genotypes, which could necessitate different desiccation management strategies for the two sunflower types.

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